Response to RC1:

Rezaei et al. use climate model simulations to investigate the impacts of stratospheric aerosol injection (SAI) on the Middle East and North African (MENA) region. The study looks specifically at total water storage, and associated hydrology variables, in model simulations with SAI and climate change. MENA is an understudied region in the context of SAI, with important potential impacts on the water cycle, so this paper is a welcome addition to the literature. The paper overall needs reorganization and edits to the text for clarity, as well as modifications to the figures and explanation of statistical methods to better communicate the results. General comments are listed first, and further specific comments below.

Reply: We sincerely appreciate your effort and time in detailed reviewing our manuscript as well as constructive comments/suggestions. We have attempted to revise the manuscript in the light of your suggestions/comments. The following is also the point–point response to all the comments (comments are rewritten in black color and their corresponding replies in red).

General comments:

- I enjoyed reading about the study area in section 2.1 (in particular, the first two paragraphs). It would be informative to return to this context in the discussion section and talk about how the results in this paper might impact the regional climate more broadly.

Reply: Agreed. We have done this now in several places in the discussion, in particular with new text below.

"In response to high GHG emissions over the 2071-2100 period, TWS decreases in the wetter regions (i.e., around the Caspian and Mediterranean Seas with mild wet winters and warm to hot, dry summers) while, on the whole, it increases or shows no significant change in the MENA, housing several major deserts with minimal precipitation."

"Given the prevailing water scarcity challenges in many regions of the Middle East, SAI may offer a potential strategy to augment the regional water resources across the area, particularly in the dry regions of Iran (containing the Lut desert in the central region and the Kavir desert in the east), Iraq, and the Arabian Peninsula (housing the Arabian Desert) as compared with the pure GHG forced scenario."

"The MENA region contains several deserts such as the Sahara in NA, the Arabian in the Arabian Peninsula, and the Lut and Kavir in Iran. As a result, it features several dust hotspots (Mousavi et al., 2023). One noteworthy aspect of our findings is the projection of higher water storage, increased soil moisture, and enhanced vegetation coverage under the solar geoengineering (SAI) scenario relative to historical conditions. This evidence holds the promise of potentially reducing dust concentrations in MENA in the future, in line with reduced dust concentrations projections made by Mousavi et al. (2023) using the GLENS project."

It would be helpful to give additional context for why these specific CESM simulations were used here (e.g., instead of the large ensemble simulations like GLENS/ARISE). I think a novelty of Tilmes et al. 2020 was the overshoot scenario but I don't believe those simulations were used here. I suggest adding some additional text in section 2.2 for context on the model simulations.

Reply: We have added the following additional text to section 2.2:

"CESM2 ranks among the top nine models known for their accuracy in simulating global precipitation patterns, based on the Hellinger distance metric, which compares the bivariate empirical densities of CESM2 with those of 34 CMIP6 models, against historical precipitation data sourced from the Global Precipitation Climatology Centre (GPCC) (Abdelmoaty et al., 2021). CESM2 has precipitation biases about 20% lower than CESM1 (Danabasoglu et al., 2020). CESM2(WACCM6) has improved stratospheric aerosol treatment (Danabasoglu et al., 2020) that is much more consistent with observations than previous climate models (Mills et al., 2016). Furthermore, CESM2(WACCM), including improvements in the simulation of carbon and nitrogen cycles with global land carbon trends matching observations remarkably well (Danabasoglu et al., 2020), and a full ocean model (Parallel Ocean Program version 2, POP2) with modularized biogeochemistry (Marine Biogeochemistry Library, MARBL) to more fully simulate the stratospheric response to the high GHG warming in the SSP5-8.5 scenario (Koven et al., 2022)."

Ref:

Abdelmoaty, H. M., Papalexiou, S. M., Rajulapati, C. R., & AghaKouchak, A. (2021). Biases beyond the mean in CMIP6 extreme precipitation: A global investigation, Earths Future, 9, e2021EF002196.

Danabasoglu, G., Lamarque, J. F., Bacmeister, J., Bailey, D. A., DuVivier, A. K., Edwards, J., ... & Strand, W. G. (2020). The community earth system model version 2 (CESM2). Journal of Advances in Modeling Earth Systems, 12(2), e2019MS001916.

Koven, C. D., Arora, V. K., Cadule, P., Fisher, R. A., Jones, C. D., Lawrence, D. M., ... & Zickfeld, K. (2022). Multi-century dynamics of the climate and carbon cycle under both high and net negative emissions scenarios. Earth System Dynamics, 13(2), 885-909.

Generally, the paper does a good job specifying which comparison is being made (e.g., SSP relative to historical or SAI relative to historical) but there are some additional places to clarify the text in the results and discussion sections, which will make these sections easier to follow and interpret. I have some specific suggestions in the comments below.

The discussion section currently recaps/repeats many of the results (e.g., Lines 485-507). I suggest focusing on interpreting the results, highlighting particularly interesting results, and connecting with previous studies. Some of this is already present in the discussion section (e.g., Lines 438-442, 475-483, 509-518), so I think the section just needs some edits to move results into the results section and focus the discussion.

Reply: We have greatly revised the discussion. We moved the following paragraphs into the results (Section 3.1):

"We also compared the changes in TWS with changes in precipitation, temperature, real ET, soil moisture, and potential ET over each region under both global warming and SAI scenarios (Figs. S2 to S6 in the Supplementary Information). The TWS decreasing patterns under both SSP5-8.5 and SSP5-8.5-SAI scenarios across the entire study area are similar to soil moisture change patterns (Fig. S2 and S4 in Supplementary Information) but more widespread than precipitation under global warming (Fig. S4). The decreased TWS is seen beyond the regions of reduced precipitation (Fig. S4), from beyond the Mediterranean and Atlantic coasts to include Syria, Iraq, and the lands around the Caspian Sea as well as to a wide portion of NA (Fig. 4). These include places where precipitation is either increasing or shows no significant change, consistent with results reported by Cook et al. (2020).

In Summary, our findings show that the SSP5-8.5-SAI scenario has potential to partially offset the significant changes in mean TWS imposed by SSP5-8.5 over the entire MENA. While SAI (Fig. 3d) succeeded in reversing mean TWS deficits in the wetter lands around the Caspian and Mediterranean Seas driven by the GHG SSP5-8.5 scenario (Fig. 3b), it did not fully cancel out the TWS deficits (Figs., 3c, 4a, and 4c). However, in the dry MENA regions (Fig. 3d), particularly Iran (containing the Lut desert in the central region and the Kavir desert in the east), Iraq, and the Arabian Peninsula (housing the Arabian Desert), SAI resulted in higher mean water storage relative to the historical period (Figs. 3c and 4)."

In addition, we also revised following parts of the discussion:

"In response to high GHG emission over the 2071-2100 period, the mean TWS decreases in the wetter regions (i.e., around the Caspian and Mediterranean Seas with mild wet winters and warm to hot, dry summers) while, on the whole, it increases or shows no significant change in the MENA, housing several major deserts with minimal precipitation. Similarly, a decrease in precipitation (Kim and Byun, 2009), surface runoff (Cook et al., 2020), and TWS (Pokhrel et al., 2021) has been reported across Mediterranean coasts under GHG warming. The mean TWS increase in the southern MENA is consistent with other climate model simulations showing increased precipitation and soil moisture in CMIP6 simulations under SSP5-8.5 (Cook et al., 2020), and SSP2-4.5 (Ajjur et al., 2021; Scanlon et al., 2023). This further aligns with a projected northward shift of the inter-tropical convergence zone (ITCZ), leading to increased moisture transfer to the Southern Middle East and North Africa (Waha et al., 2017). The CMIP6 models have consistently projected a substantial northward shift of the ITCZ in eastern Africa, mostly during the months of May to October (Mamalakis et al., 2021)."

"By mitigating the vulnerability to global warming, particularly in MENA where population growth is a continuing concern (Oroud, 2008), SAI interventions could play a crucial role in water resource management and adaptation strategies. Similarity, Jones et al. (2018) found that SAI could effectively counteract the changes in available water imposed by global warming on Earth's lands."

"The MENA region contains several deserts such as the Sahara in NA, the Arabian in the Arabian Peninsula, and the Lut and Kavir in Iran. As a result, it features several dust hotspots (Mousavi et al., 2023). One noteworthy aspect of our findings is the projection of higher water storage, increased soil moisture, and enhanced vegetation coverage under the solar geoengineering (SAI) scenario relative to historical conditions. This evidence holds the promise of potentially reducing dust concentrations in MENA in the future, in line with reduced dust concentrations projections made by Mousavi et al. (2023) using the GLENS project"

"The more robust and widespread deficit in mean TWS compared to precipitation in the area, which is in line with results reported by Cook et al. (2020), highlights the profound roles that other variables/processes have on the increased ET such as greater atmospheric moisture demand (Dai et al., 2013, 2018) and greater vegetation water use (Mankin et al., 2019) owing to warmer conditions under global warming, consistent with regression model results."

"The vegetation coverage as the primary variable influencing changes in TWS within the area (except for the eastern NA) substantially increases under global warming (Figures S6 and S7). It has an important, but often complex and uncertain, role in surface water content (Lemordant et al., 2018; Trugman et al., 2018); the denser vegetation coverage, the higher evapotranspiration rates."

"This is consistent with MLR model results (Fig. 7a) in which, beyond the precipitation, temperature also plays an important role in TWS across R1. Similarly, while precipitation on lands decreases under SAI relative to global warming, the evaporation decreases are stronger, resulting in a net increase in surface water (Irvine et al., 2016). These regional nuances underscore the necessity of tailored water management strategies to address the complex interplay of these variables."

"Our findings, on the whole, suggest that the specific SAI scenario considered here helps water storage in the dry regions (R2, R4, R5, and R6), i.e., leads to higher soil moisture and TWS compared with both the historical conditions and pure GHG-induced global warming. Likewise, Dagon and Scharg (2017) documented a rise in mean water availability and soil moisture during the period of June to August in MENA using SolarGeo simulations. This works through the combined positive effects of (1) a substantial decrease in temperature and ET over the entire study area compared with SSP5-8.5 global warming, consistent with the significant reduction in daily maximum temperatures and ET across the Middle East, leading to increased soil water under SAI (Dagon and Scharg, 2017) and (2) the increased precipitation in the southern MENA dry regions relative to historical conditions. The Middle East may therefore benefit from the water enrichment from climate change through the implementation of solar intervention (Burnell, 2021)."

"However, the wet and colder regions, particularly around the Mediterranean coasts, may have less water storage compared with the historical period but more water relative to the GHG scenario due to a significant decrease in evapotranspiration under SAI. Simpson et al. (2019) also reported a noteworthy decline of 18.5% in available water (precipitation minus evaporation) across the Mediterranean area under high GHG emissions while it has been partially reversed (only 5%) by decrease in evaporation imposed by GLENS SAI project."

"Although SAI partially compensates for the extreme TWS changes in most of the study area, aligning with the global findings by Jones et al. (2018), the overall extreme TWS trend indicates an increase in dry regions of Iran and Iraq, Arabian Peninsula, and western NA."

New Ref:

Burnell, L. (2021). Risks to global water resources from geoengineering the climate with solar radiation management (Doctoral dissertation, University of Nottingham).

Dagon, K., & Schrag, D. P. (2017). Regional climate variability under model simulations of solar geoengineering. Journal of Geophysical Research: Atmospheres, 122(22), 12-106.

Irvine, P. J., Kravitz, B., Lawrence, M. G., & Muri, H. (2016). An overview of the Earth system science of solar geoengineering. Wiley Interdisciplinary Reviews: Climate Change, 7(6), 815-833.

Jones, A. C., Hawcroft, M. K., Haywood, J. M., Jones, A., Guo, X., & Moore, J. C. (2018). Regional climate impacts of stabilizing global warming at 1.5 K using solar geoengineering. Earth's Future, 6(2), 230-251.

Lemordant, L., Gentine, P., Swann, A. S., Cook, B. I., & Scheff, J. (2018). Critical impact of vegetation physiology on the continental hydrologic cycle in response to increasing CO2. Proceedings of the National Academy of Sciences, 115(16), 4093. https://doi.org/10.1073/pnas.1720712115.

Mamalakis, A., Randerson, J.T., Yu, J.-Y., Pritchard, M.S., Magnusdottir, G., Smyth, P. et al. (2021) Zonally opposing shifts of the intertropical convergence zone in response to climate change, 45.

Mousavi, S. V., Karami, K., Tilmes, S., Muri, H., Xia, L., and Rezaei, A. (2023). Future dust concentration over the Middle East and North Africa region under global warming and stratospheric aerosol intervention scenarios, Atmos. Chem. Phys., 23, 10677–10695, https://doi.org/10.5194/acp-23-10677-2023

Pokhrel, Y., Felfelani, F., Satoh, Y., Boulange, J., Burek, P., Gädeke, A., ... & Wada, Y. (2021). Global terrestrial water storage and drought severity under climate change. Nature Climate Change, 11(3), 226-233.

Trugman, A. T., Medvigy, D., Mankin, J. S., & Anderegg, W. R. L. (2018). Soil moisture stress as a major driver of carbon cycle uncertainty. Geophysical Research Letters, 45, 6495–6503. https://doi.org/10.1029/2018GL078131

Waha, K., Krummenauer, L., Adams, S., Aich, V., Baarsch, F., Coumou, D. et al. (2017) Climate change impacts in the Middle East and northern Africa (MENA) region and their implications for vulnerable population groups. Regional Environmental Change, 17(6), 1623–1638. Available from: https://doi.org/10.1007/s10113-017-1144-2

Specific comments:

Lines 68-72: This paragraph seems out of place. Suggest moving this down to where projected future changes in the Mediterranean are discussed (e.g., Line 96).

Reply: Implemented.

Lines 74-84: Moving this paragraph down to after the discussion on climate change impacts (e.g., Line 108) would then transition to an introduction to SRM and associated impacts.

Reply: Implemented.

Line 90: Are there any more recent modeling studies (e.g., CMIP5 or CMIP6) that discuss projected changes in the MENA region? If not, it is worth pointing that out.

Reply: Here we focused on CMIP6 literature for consistency. Please see the revised version of these section copied below:

"Using GHG emission scenario A1B simulated by nine CMIP3-class climate models, Droogers et al. (2012) projected that 22% of the future annual water shortage, 199 km3 in 2050 in MENA, will be due to global warming. 17 global climate models from CMIP6 under SSP5-8.5 simulate a significant increase in precipitation (+0.05 to 0.3 $\mp$ 0.1 mm day^{-1}) over South-Eastern Saharan Desert in North Africa by the end of the century (Arjdal et al., 2023). They also projected that the total soil moisture would increase over Southern Saharan Desert under the SSP5-8.5 (6 to 20%) and SSP2-4.5 (4 to 14%). Based on TWS data from eight global climate models belonging to CMIP6, a broad part of the dry MENA region tends to be wetter under SSP5-8.5 over 2071-2100 (Xiong et al., 2022)."

Line 102: An explanation of "soil moisture z-scores" is needed here.
Reply: Implemented. We added the following explanation to the text.
"It is computed by subtracting the mean and dividing by the standard deviation of the time series from the baseline period".

Line 162: This is covered in the introduction; suggest removing this sentence and moving the second sentence of this paragraph into the preceding paragraphs on the discussion of regional climate.
Reply: Implemented.

Line 174: In addition to defining "real evapotranspiration", please add an explanation on "potential evapotranspiration" and how that is calculated since that is also listed in Table 1. Is real ET a model output and potential ET is calculated from model output?
Reply: Real and potential ET have been calculated. We added the following explanations to the new version:
"Potential evapotranspiration (ET) is the amount of evaporation that would occur if a sufficient water source were available. The Thornthwaite method was used to calculate the potential ET based on the monthly mean temperature and latitude data for each grid. Water evaporation from both soil and canopy and transpiration are summed up to obtain the real ET."

Table 1: The caption mentions historical model output as the data source for this table – please add this to the text as well (e.g., Line 172). It might also make sense for Table 1 to come after the model is introduced in section 2.2.
Reply: We added it to the text as well. However, we believe that Table 1 position in the Study area section is more appropriate.

Line 209: Please clarify the text here – what is meant by "in turn"?
Reply: It means "and consequently". We simply deleted this as follows:
"For the anomaly analysis relative to historical conditions and the multiple linear regression models, we used the first three ensembles of SSP5-8.5 …"

Line 241: Was this correlation calculated or made by eye using the plots in Figure S2? And was the correlation tested for the other variable combinations? Calculating the correlations and reporting them in the paper would make for a stronger justification of the MLR model inputs.
Reply: We have calculated the correlation coefficients. Please see the following results. Except for region 5, the correlation coefficient between TWS and soil moisture in all regions under all scenarios and ensembles are larger than 0.90. The correlation coefficient between temperature and soil moisture in all cases is larger than 0.90 and statistically significant at the 5% level. However, we added these correlation values to the text and also included the following tables in the Supplementary Information.

Table S2. The average correlation between the variables under the available ensembles for global warming SSP5-8.5 scenario in the region R1. Consistently, the values inside the parenthesis are the difference-range values between minimum and maximum correlations. The insignificant correlation coefficients (p-value>0.05) are underlined.

SSP-R1	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	-0.35 (-0.31, -0.37)	0.61 (0.58, 0.64)	0.99 (0.98, 1)	0.18 (0.15, 0.23)	-0.30 (-0.26, -0.32)	0.77 (0.72, 0.78)
Temp		1	-0.61 (-0.60, -0.62)	-0.35 (-0.32, -0.37)	0.77 (0.76, 0.78)	0.96 (0.96, 0.96)	0.05 (0.02, 0.07)
Precip			1	0.59 (0.56, 0.63)	-0.17 (-0.13, -0.19)	-0.56 (-0.55, -0.57)	0.42 (0.40, 0.44)
SM				1	0.17 (0.14, 0.22)	-0.30 (-0.26, -0.32)	0.74 (0.70, 0.77)
RET					1	0.75 (0.75, 0.75)	0.60 (0.58, 0.63)
PET						1	0.11 (0.08, 0.13)
LAI							1

Table S3. As Table S2 but for the region R2.

SSP-R2	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	-0.25 (-0.24, -0.26)	0.50 (0.47, 0.53)	0.99 (0.99, 1)	0.54 (0.50, 0.57)	-0.24 (-0.23, -0.25)	0.72 (0.71, 0.74)
Temp		1	-0.48 (-0.47, -0.50)	-0.24 (-0.22, -0.25)	0.11 (0.10, 0.12)	0.95 (0.94, 0.96)	-0.18 (-0.15, -0.20)
Precip			1	0.49 (0.46, 0.51)	0.53 (0.52, 0.55)	-0.51 (-50, -53)	0.52 (0.51, 0.53)
SM				1	0.53 (0.49, 0.56)	-0.22 (-0.20, -0.24)	0.71 (0.70, 0.73)
RET					1	0.03 (0.02, 0.04)	0.85 (0.84, 0.86)
PET						1	0.16 (0.14, 0.19)
LAI							1

Table S4. As Table S2 but for the region R3.

SSP-R3	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	-0.67 (-0.65, -0.70)	0.51 (0.49, 0.52)	0.98 (0.97, 0.99)	0.34 (0.33, 0.35)	-0.54 (-0.52, -0.57)	0.80 (0.78, 0.81)
Temp		1	-0.83 (-0.82, -0.84)	-0.68 (-0.66, -0.70)	0.23 (0.22, 0.24)	0.97 (0.97, 0.97)	-0.44 (-0.42, -0.46)
Precip			1	0.49 (0.46, 0.51)	-0.28 (-0.27, -0.30)	-0.82 (-0.81, -0.83)	0.31 (0.29, 0.32)
SM				1	0.34 (0.33, 0.35)	-0.55 (-0.53, -0.57)	0.80 (0.78, 0.81)
RET					1	0.33 (0.32, 0.34)	0.69 (0.68, 0.70)
PET						1	-0.29 (-0.26, -0.31)
LAI							1

Table S5. As Table S2 but for the region R4.

SSP-R4	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	0.08 (0.03, 0.11)	0.19 (0.14, 0.23)	0.99 (0.98, 1)	0.35 (0.26, 0.42)	0.08 (0.05, 0.10)	0.53 (0.43, 0.59)
Temp		1	-0.06 (-0.02, -0.11)	0.08 (0.04, 0.11)	0.04 (0.03, 0.06)	0.92 (0.92, 0.92)	-0.07 (-0.02, -0.12)
Precip			1	0.18 (0.13, 0.22)	0.71 (0.68, 0.72)	-0.14 (-0.10, -0.20)	0.25 (0.23, 0.27)
SM				1	0.32	0.08	0.53

					(0.21, 0.40)	(0.06, 0.10)	(0.42, 0.59)
RET					1	-0.09 (-0.05, -0.13)	0.62 (0.60, 0.64)
PET						1	0.04 (0.01, 0.06)
LAI							1

Table S6. As Table S2 but for the region R5.

SSP-R5	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	0.15 (0.14, 0.17)	0.19 (0.15, 0.23)	0.74 (0.70, 0.76)	0.29 (0.24, 0.33)	0.19 (0.18, 0.21)	0.33 (0.29, 0.35)
Temp		1	0.17 (0.12, 0.24)	0.31 (0.24, 0.37)	0.34 (0.31, 0.39)	0.96 (0.96, 0.96)	0.50 (0.46, 0.53)
Precip			1	0.36 (0.31, 0.38)	0.91 (0.88, 0.93)	0.12 (0.07, 0.19)	0.61 (0.54, 0.70)
SM				1	0.49 (0.41, 0.55)	0.32 (0.25, 0.38)	0.50 (0.43, 0.55)
RET					1	0.30 (0.27, 0.36)	0.82 (0.79, 0.85)
PET						1	0.47 (0.44, 0.50)
LAI							1

Table S7. As Table S2 but for the region R6.

SSP-R6	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	0.29 (0.26, 0.31)	0.29 (0.24, 0.35)	0.98 (0.97, 1)	0.46 (0.38, 0.53)	0.26 (0.21, 0.31)	0.26 (0.24, 0.31)
Temp		1	0.06 (0.02, 0.11)	0.29 (0.26, 0.31)	0.32 (0.27, 0.39)	0.95 (0.94, 0.96)	0.35 (0.28, 0.40)
Precip			1	0.27 (0.22, 0.32)	0.84 (0.82, 0.85)	0.04 (0.02, 0.07)	-0.02 (0.00, -0.06)
SM				1	0.43 (0.36, 0.50)	0.28 (0.26, 0.30)	0.27 (0.24, 0.32)
RET					1	0.26 (0.23, 0.30)	0.05 (0.03, 0.11)
PET						1	0.22 (0.12, 0.29)
LAI							1

Table S8. As Table S2 but under SAI scenario for the region R1.

SAI-R1	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	-0.20 (-0.18, -0.24)	0.59 (0.58, 0.60)	0.96 (0.95, 0.97)	0.13 (0.13, 0.13)	-0.15 (-0.13, -0.18)	0.52 (0.46, 0.59)
Temp		1	-0.51 (-0.49, -0.52)	-0.06 (-0.02, -0.11)	0.88 (0.87, 0.89)	0.96 (0.96, 0.96)	0.44 (0.38, 0.49)
Precip			1	0.53 (0.52, 0.54)	-0.20 (-0.19, -0.21)	-0.47 (-0.46, -0.49)	0.26 (0.23, 0.28)
SM				1	0.26 (0.25, 0.27)	-0.05 (0.00, -0.08)	57 (50, 64)
RET					1	0.89 (0.88, 0.90)	0.76 (0.72, 0.78)
PET						1	0.52 (0.46, 0.57)
LAI							1

Table S9. As Table S2 but under SAI scenario for the region R2.

SAI-R2	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	-0.26 (-0.24, -0.28)	0.53 (0.51, 0.55)	0.97 (0.96, 1)	0.54 (0.52, 0.57)	-0.25 (-0.23, -0.26)	0.73 (0.69, 0.79)
Temp		1	-0.53	-0.24	0.27	0.96	-0.08

	TWS	Temp	Precip	SM	RET	PET	LAI
			(0.51, 0.55)	(-0.22, -0.26)	(0.26, 0.28)	(0.96, 0.96)	(-0.05, -0.09)
Precip			1	0.51 (0.50, 0.53)	0.41 (0.40, 0.42)	-0.57 (-0.54, -0.59)	0.50 (0.48, 0.51)
SM				1	0.53 (0.51, 0.56)	-0.23 (-0.21, -0.24)	0.72 (0.68, 0.78)
RET					1	0.21 (0.21, 0.22)	0.84 (0.84, 0.84)
PET						1	-0.04 (-0.03, -0.05)
LAI							1

Table S10. As Table S2 but under SAI scenario for the region R3.

SAI-R3	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	-0.54 (-0.53, -0.55)	0.43 (0.42, 0.44)	0.98 (0.97, 0.99)	0.25 (0.24, 0.26)	-0.46 (-0.46, -0.47)	0.76 (0.75, 0.77)
Temp		1	-0.78 (0.78, 0.79)	-0.54 (-0.53, -0.55)	0.55 (0.54, 0.56)	0.98 (0.96, 0.99)	-0.18 (-0.16, -0.19)
Precip			1	0.42 (0.41, 0.43)	-0.37 (-0.35, -0.38)	-0.78 (-0.78, -0.78)	0.18 (0.17, 0.21)
SM				1	0.26 (0.25, 0.26)	-0.46 (-0.46, -0.47)	0.76 (0.75, 0.78)
RET					1	0.59 (0.58, 0.59)	0.67 (0.66, 0.67)
PET						1	-0.09 (-0.07, -0.10)
LAI							1

Table S11. As Table S2 but under SAI scenario for the region R4.

SAI-R4	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	0.03 (0.01, -0.04)	0.28 (0.27, 0.30)	0.99 (0.98, 1)	0.45 (0.37, 0.52)	0.03 (0.02, 0.04)	0.56 (0.52, 0.60)
Temp		1	-0.05 (-0.02, -0.07)	0.03 (0.01, 0.04)	0.09 (0.06, 0.10)	0.94 (0.94, 0.94)	0.16 (0.10, 0.24)
Precip			1	0.27 (0.26, 0.29)	0.78 (0.76, 0.79)	-0.14 (-0.11, -0.15)	0.32 (0.26, 0.36)
SM				1	0.43 (0.36, 0.50)	0.03 (0.02, 0.04)	0.55 (0.51, 0.59)
RET					1	-0.02 (0.00, -0.03)	0.68 (0.67, 0.69)
PET						1	0.15 (0.08, 0.23)
LAI							1

Table S12. As Table S2 but under SAI scenario for the region R5.

SAI-R5	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	0.29 (0.22, 0.34)	0.15 (0.14, 0.16)	0.73 (0.64, 0.80)	0.28 (0.26, 0.31)	0.33 (0.27, 0.38)	0.36 (0.28, 0.41)
Temp		1	0.12 (0.12, 0.13)	0.29 (0.24, 0.34)	0.36 (0.35, 0.37)	0.97 (0.97, 0.97)	0.56 (0.52, 0.59)
Precip			1	0.37 (0.33, 0.41)	0.88 (0.88, 0.89)	0.09 (0.09, 0.10)	0.56 (0.52, 0.58)
SM				1	0.54 (0.50, 0.58)	0.32 (0.26, 0.37)	0.50 (0.46, 0.54)
RET					1	0.34 (0.32, 0.35)	0.80 (0.77, 0.81)
PET						1	0.56 (0.52, 0.59)
LAI							1

Table S13. As Table S2 but under SAI scenario for the region R6.

SAI-R6	TWS	Temp	Precip	SM	RET	PET	LAI
TWS	1	0.11 (0.06, 0.17)	0.26 (0.19, 0.31)	0.99 (0.98, 1)	0.44 (0.38, 0.50)	0.11 (0.05, 0.16)	0.33 (0.31, 0.35)
Temp		1	0.06 (0.05, 0.08)	0.11 (0.06, 0.17)	0.35 (0.33, 0.37)	0.96 (0.96, 0.96)	0.37 (0.34, 0.40)
Precip			1	0.24 (0.18, 0.29)	0.73 (0.72, 0.74)	0.00 (0.00, 0.00)	0.08 (0.03, 0.12)
SM				1	0.42 (0.36, 0.47)	0.10 (0.05, 0.16)	0.33 (0.31, 0.34)
RET					1	0.29 (0.26, 0.31)	0.26 (0.19, 0.30)
PET						1	0.32 (0.30, 0.35)
LAI							1

Line 246: How often / how many outliers were removed using this method?
Reply: We totally fitted 36 models. The number of outliers removed is specific for each model. In some models, no outliers were detected while in others up to 5 data points were removed. We added the following sentence to the manuscript:
"The number of outlier data points excluded varies from zero to 5 in the 36 models."

Line 254: Please add more details on the method here – specifically what is meant by "independent variable-order average over average contributions…" and "impacts adjusted for other regressors".
Reply: "independent variable-order average over average contributions…" refers to the fact that the order in which variables are added to the model can affect how much each variable contributes to the overall R-squared. If a variable that has a strong linear relationship with the dependent variable be initially added, it may capture a significant portion of the variance, which can affect the subsequent contributions of other variables. To mitigate the order dependency, the LMG calculates average contributions by considering all possible orders and then averaging the results. This approach helps provide a more robust estimate of variable importance that is less sensitive to the specific order in which variables are considered. For clarity we revised this sentence as follows:
"The LMG method considers the average contributions of each variable across different model sizes and then averages these averages to provide a more robust measure of variable importance."

To clarify the "impacts adjusted for other regressors" term we have added the following additional description to the text:
"As the considered variables may be correlated with each other, when a new predictor is added to a model that already contains other predictors, its impact can be influenced by the presence of those other variables. The LMG method takes into account these interactions and adjusts the variable's contribution to reflect its unique impact while considering the effects of other regressors."

Figure 2: It is difficult to see the trends in the anomalies with the strong seasonal cycle in certain regions. Suggest removing the seasonal cycle and/or some other method of filtering out noise here (e.g., running yearly means).

Reply: We have also extracted the long-term trends using Singular Spectrum Analysis (SSA) method (below figure), consistent with the results from Figure 2. This figure has also been included in the Supplementary Information.

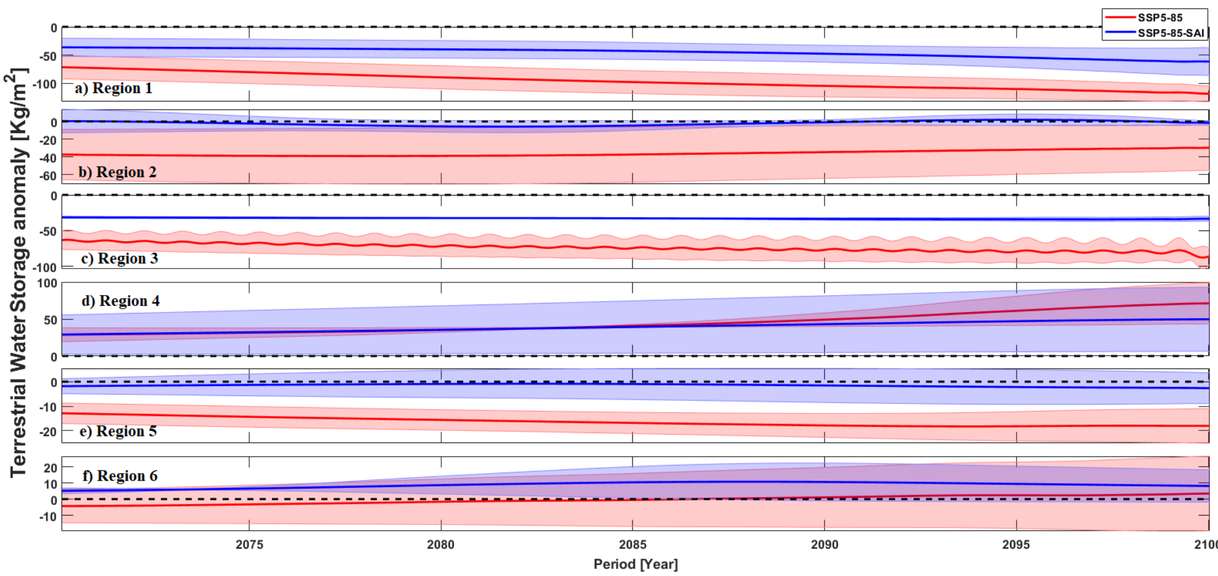

Figure RC1-1. The long-term trends of TWS anomaly relative to the TWS averaged over the historical period across MENA and the lands around the Caspian and Mediterranean Seas under global warming without (SSP5-8.5) and with SAI (SSP5-8.5-SAI). Figures a-f respectively are for regions R1 to R6. Shading in each curve shows the across-ensemble range. The dashed line crossing the *y*-axis at zero in each subplot is the ensemble mean of TWS over the historical period (1985-2014).

Lines 282-295: Please use the region labels (e.g., R1-R6) in the text here to ease the interpretation of Figure 3.
Reply: Implemented (please see new Figure 3 on the next page).

Line 292: Clarify "Mean TWS" here – is that the temporal mean, ensemble mean, spatial mean, or some combination?
Reply: It refers to temporal-ensemble mean.

Figure 3 (and others): For the difference plots (e.g., panels b-d), I recommend choosing a different color scale with a clear divergence at 0. With this yellow/blue color scale it is difficult to discern positive vs. negative regions of change. Same comment for Figures S2, S4. The color scale in Figure S1 works better for difference plots.
Reply: Implemented. As an example, please see new Figure 3.

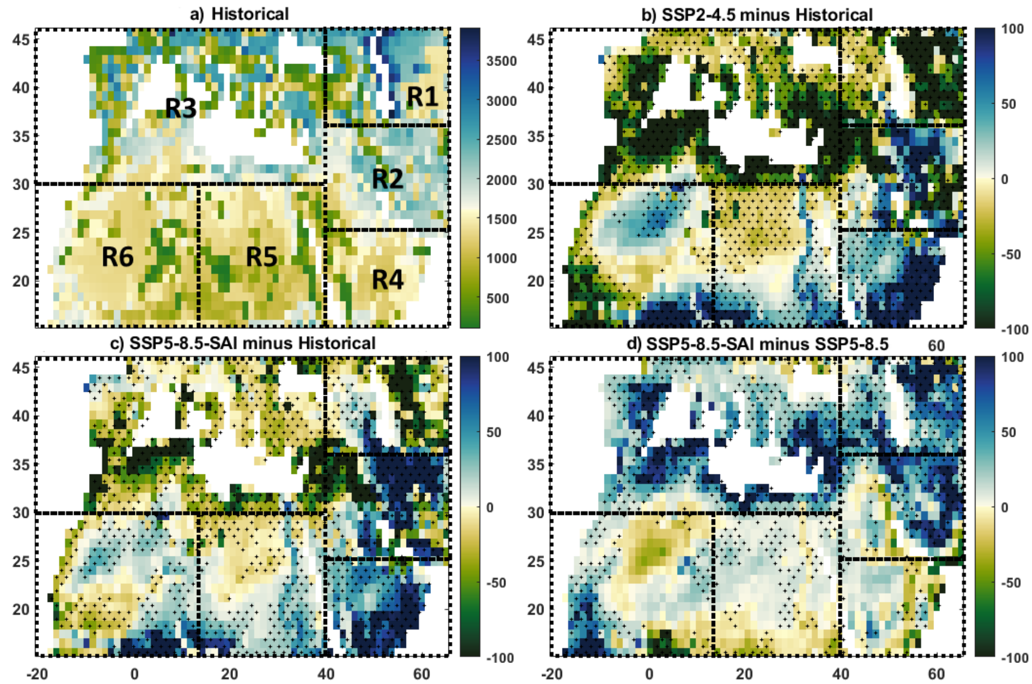

Figure 3. Ensemble mean maps of TWS across the studied domain in the historical climate (a) over 1985-2014 and their projected future changes in the 2071–2100 period under the SSP5-85 GHG scenario (SSP5-8.5 minus historical (b) and GHG+SAI minus historical (c)). The extent to which the SAI impacts the TWS changes imposed by global warming is further shown (SAI minus SSP5-8.5 (d)). Hatched areas show where all ensemble members agree on the sign of the changes.

Lines 304-311: Use percentage values instead of absolute kg/m^2 changes in the text here to match the black labels in Figure 4. Or use absolute labels in Figure 4, which would match the y-axis.

Reply: We have used percentage in the text in the new version as follows:

"Mean TWS significantly ($p<0.05$) decreases in the wetter lands around the Caspian (R1) and Mediterranean (R3) Seas to the north (3.7-5.2% on area average) while it significantly increases in the dry region of Arabian Peninsula (5.6%) in response to GHG warming."

Figure 4: In addition to the partial reversals (R1, R3, R4) and the overcompensation (R2), SAI also has an amplifying effect in R5 and a slight overcompensation in R6 – it is worth noting these responses in the text (even if to say they are not significant).

Reply: The following sentence has been added to the text:

"SAI also has an amplifying effect in R5 and a slight overcompensation in R6, but its impact is statistically insignificant."

Figure 4: Why are there three p-values shown at the bottom of each panel? I assume two of the values denote the significance of the changes in SSP and SAI relative to historical, but what does the other value represent? Please clarify in the figure caption. Same comment for Figures S3 and S5.

Reply: Implemented. The new caption for Figure 4 is copied below:

“Figure 4. Box and whiskers plot of the changes in the Terrestrial Water Storage (TWS) in regions 1 to 6 over 2071-2100 under SSP5-8.5 and SSP5-8.5-SAI relative to historical conditions (1985-2014). The titles of each subplot refer to the regions. The median for each experiment is denoted by the red line, the upper (75th) and lower (25th) quartiles by the top and bottom of the box, and ensemble limits by the whisker extents. The positive/negative values in black are the change percent under SSP5-8.5 and SSP5-8.5-SAI relative to the median of the historical period data. The three values in green refer to p-values between historical and global warming, historical and SAI, and global warming and SAI, respectively, obtained from t-test analysis in which the underlined p-values are statistically significant.”

Line 330: Similar question to Line 241 – was significance calculated here or by eye? Why do non-overlapping curves imply significance?

Reply: We first conducted the repeated measures analysis of variance which compares means across one or more variables that are based on repeated observations, and then performed post hoc Tukey-Kramer comparisons to determine which curves (including its upper and lower bounds) are significantly different from each other (please see the new Figure 5 below). However, we have added the above explanations to the text.

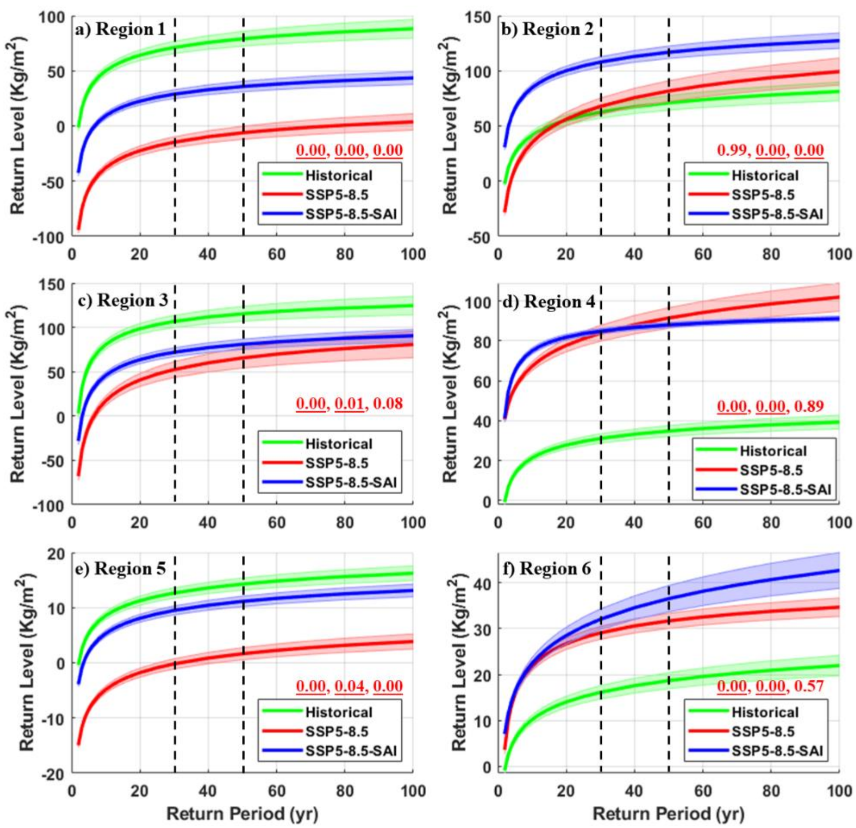

Figure 5. The TWS anomaly return level versus return period using the first three realizations for the historical, SSP5-8.5, and SSP5-8.5-SAI in regions 1 to 6 (a to f). The two parallel dashed black lines refer to 30- (left) and 50-year (right) return periods. Shading in each curve is the 95% upper and lower confidence bands. The three values in red refer to *p*-values between historical and global warming, historical and SAI, and global warming and SAI, respectively, obtained from the repeated measures analysis of variance and the post hoc Tukey-Kramer comparisons in which the underlined *p*-values are statistically significant.

Lines 344-360: Please use the region labels R1-R6 in text here to ease comparison to Table 2.
Reply: Implemented. Please see the revised version of this part copied below:
"Global warming, on the whole, decreases the TWS extremes (i.e., fewer wetter conditions) at 30- to 100-year return periods over all the study areas except for the Arabian Peninsula (R4) and western NA (R6). The most robust decreases in the extreme TWS imposed by global warming relative to historical conditions occur in the lands around the Caspian R1 (-108% on average over return periods from 30- to 100-year) and Mediterranean R3 (-43% on average) and the eastern NA R5 (-89% on average) are partially suppressed by SAI. A small increase in the extreme TWS in Iran and Iraq (R2) simulated under GHG (+15%) is overcompensated by SAI (+57%)."

Line 346 and following: Please clarify "decreases the TWS extremes" – does this mean a decrease in positive extremes (i.e., fewer wetter conditions) or negative extremes (fewer drier conditions) or both?
Reply: Note that return levels refer to the peaks in the TWS time series. Since here we used the anomalies relative to the historical mean, the peaks may be negative or positive. However, here we mean the fewer wetter conditions. Please see the following revised part:
"Global warming, on the whole, decreases the TWS extremes (i.e., fewer wetter conditions) at 30- to 100-year return periods …".

Lines 378-380: Please clarify here whether this is referring to the most important variable under SAI or SSP (or both).
Reply: Under both SSP and SAI.

Lines 386-389: Please clarify what is meant by "due to evapotranspiration" if this is looking only at temperature and precipitation ("with just temperature and precipitation as independent variables"). Are there results that look at subsets of these three variables and are they included somewhere?
Reply: Our mean of "With just temperature and precipitation as independent variables, …" is that if we compare the temperature importance role on TWS with precipitation role. We just want to know between precipitation and temperature which one is more important. However, in all TWS MLR models, all four variables of real ET, precipitation, temperature, and leaf area index (i.e., vegetation coverage) have been considered.

Line 399: Please include the specific variance explained values for the MLR models somewhere in the text or figures (e.g., the bars of Figure 6-7).
Reply: We have included the ensemble-mean variance on Figures 6-7.

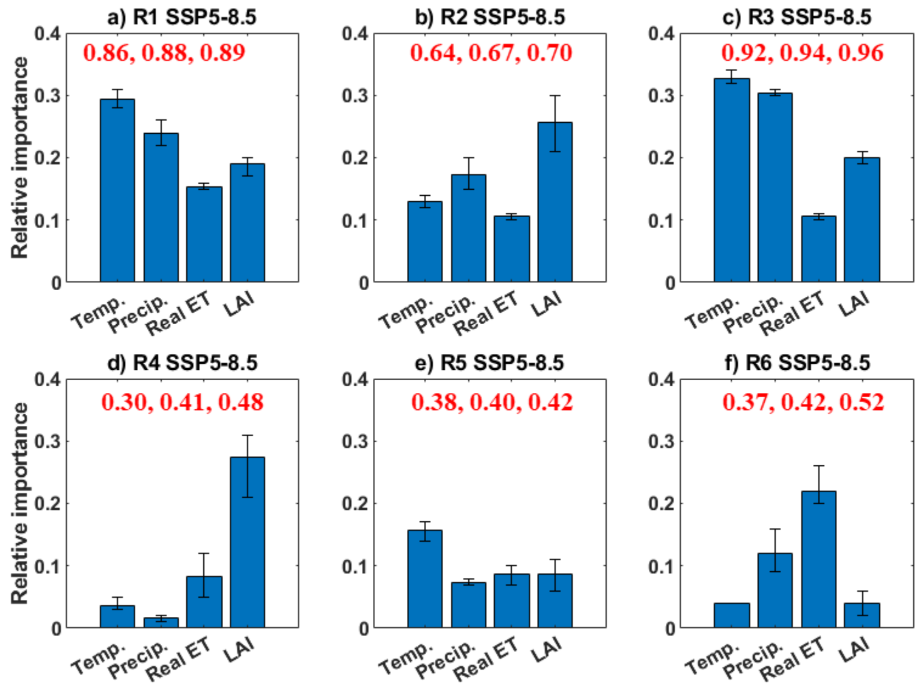

Figure 6. LMG importance plot (Lindeman et al., 1980) of the four independent variables in the regression for TWS for the global warming SSP5-8.5 scenario in each region. The bar and range-bar respectively show the ensemble mean importance and the range of importance from the three ensemble members. The three values in red on each subplot shows the minimum, mean, and maximum variances explained by models.

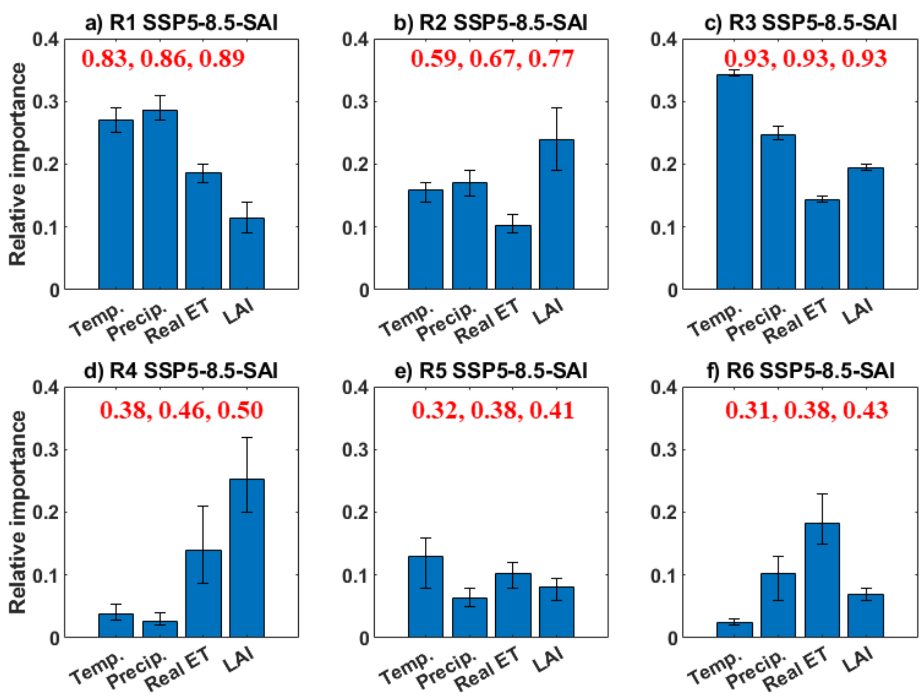

Figure 7. As in Fig. 6, but for the SSP5-8.5-SAI scenario.

Figures 6-7: Here, or perhaps in the methods section, please provide some context for the importance values (y-axis). Is this unitless, and if so, should the individual variable contributions total to 1 if all the appropriate variables were sampled? Are interactions considered?
Reply: Implemented (please see new Figures 6 and 7 above). Importance is a unitless variable and the sum of all independent variable importance's in each model equals the model's variance explained. The importance values for individual variables do not necessarily need to total to 1.
However, we have added the following sentence to the text:
"Importance is a unitless variable and the sum of all independent variable importance's in each model equals the model's explained variance."
In the case of LMG, it's a method that explicitly considers interaction effects and decomposes the total variance explained into contributions from individual variables, pairs of variables, and higher-order interactions. Therefore, LMG importance values can provide insights into both main effects and interaction effects.

Lines 444-457: Most of this paragraph should go in the results section, as the supplemental figures have not yet been discussed. The last sentence gets to a comparison with other studies which is appropriate for the discussion section and can be merged with another paragraph.
Reply: We have moved this part into the results, last part of section 3.1, as copied below:
"We also compared the changes in TWS with changes in precipitation, temperature, real ET, soil moisture, and potential ET over each region under both global warming and SAI scenarios (Figs. S2 to S6 in the Supplementary Information). The TWS decreasing patterns under both SSP5-8.5 and SSP5-8.5-SAI scenarios across the entire study area are similar to soil moisture change patterns (Fig. S2 and S4 in Supplementary Information) but more widespread than precipitation under global warming (Fig. S4). The decreased TWS is seen beyond the regions of reduced precipitation (Fig. S4), from beyond the Mediterranean and Atlantic coasts to include Syria, Iraq, and the lands around the Caspian Sea as well as to a wide portion of NA (Fig. 4). These include places where precipitation is either increasing or shows no significant change, consistent with results reported by Cook et al. (2020).
In Summary, our findings show that the SSP5-8.5-SAI scenario has a potential to partially offset the significant changes in mean TWS imposed by SSP5-8.5 over the entire MENA. While SAI (Fig. 3d) succeeded in reversing mean TWS deficits in the wetter lands around the Caspian and Mediterranean Seas driven by the GHG SSP5-8.5 scenario (Fig. 3b), it did not fully cancel out the TWS deficits (Figs., 3c, 4a, and 4c). However, in the dry MENA regions (Fig. 3d), particularly Iran (containing the Lut desert in the central region and the Kavir desert in the east), Iraq, and the Arabian Peninsula (housing the Arabian Desert), SAI resulted in higher mean water storage relative to the historical period (Figs. 3c and 4)."

Line 446: Please specify which simulation "The TWS decreasing patterns" refers to.
Reply: Both SSP5-8.5 and SSP5-8.5-SAI scenarios.

Line 461: Related to vegetation, it is worth discussing the competing impacts of high CO_2 and less solar radiation in the SAI scenario. These impacts could also be contributing to the overall ET, soil moisture, and TWS responses. The regions discussed here have varying amounts of vegetation and that could be contributing to the range of regional responses.

Reply: It has been found that considering vegetation variable for TWS leads to improved TWS model output (Trautmann et al., 2022). Plants absorb water from the soil and release it into the atmosphere through transpiration. Hence, we added leaf area index (LAI) as a new variable into MLR models and results (please see new Figures 6 and 7 above and Figures S6 and S7 below). We also used LAI findings in the discussion as copied below:

"MENA houses several deserts such as Saharan in NA, Arabian in the Arabian Peninsula, and Lut and Kavir in Iran. As a result, it features several dust hotspots (Mousavi et al., 2023). One noteworthy aspect of our findings is the projection of higher water storage, increased soil moisture, and enhanced vegetation coverage under the solar geoengineering (SAI) scenario relative to historical conditions. This evidence holds the promise of potentially reducing dust concentrations in MENA in the future, in line with reduced dust concentrations projections made by Mousavi et al. (2023) using the GLENS project.

The more robust and widespread deficit in mean TWS compared to precipitation in the area, which is in line with results reported by Cook et al. (2020), highlights the profound roles that other variables/processes have on the increased ET such as greater atmospheric moisture demand (Dai et al., 2013, 2018) and greater vegetation water use (Mankin et al., 2019) owing to warmer conditions under global warming, consistent with regression model results. According to MLR model results (Figs. 6 and 7), the projected changes in TWS were not solely attributable to precipitation; its interplay with other factors, such as vegetation coverage, temperature, and evapotranspiration play a pivotal role. The vegetation coverage as the primary variable influencing changes in TWS within the area (except for the eastern NA) substantially increases under global warming (Figures RC2 and RC3). It has an important, but often complex and uncertain, role in surface water content (Lemordant et al., 2018; Trugman et al., 2018); the denser vegetation coverage, the higher evapotranspiration rates."

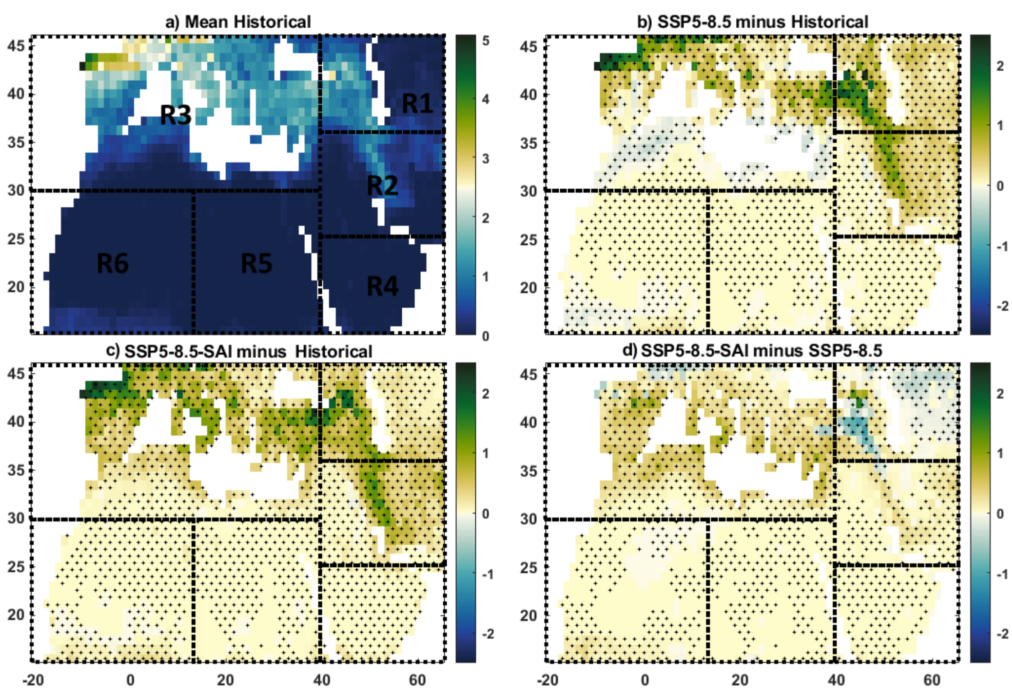

Figure S6. As Figure 3 but for LAI.

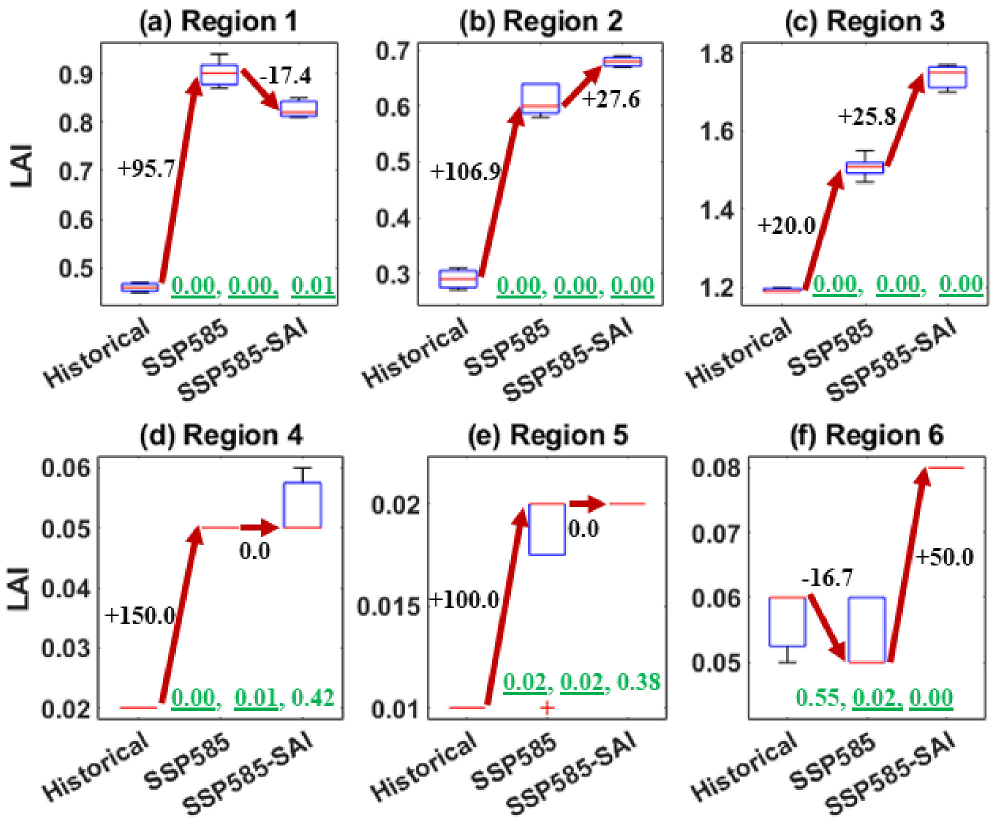

Figure S7. As Fig. 4 but for LAI.

Figure S3: I thought the middle row of this plot (TWS) would be same as Figure 4, but it appears to be different. What is plotted here and what is the difference with Figure 4?

Reply: Agreed. We rechecked and replotted Figures S3 and 4, now they are the same. It seems that in the previous version of Figure S3 was an initial plot after which I edited some parts of the code.

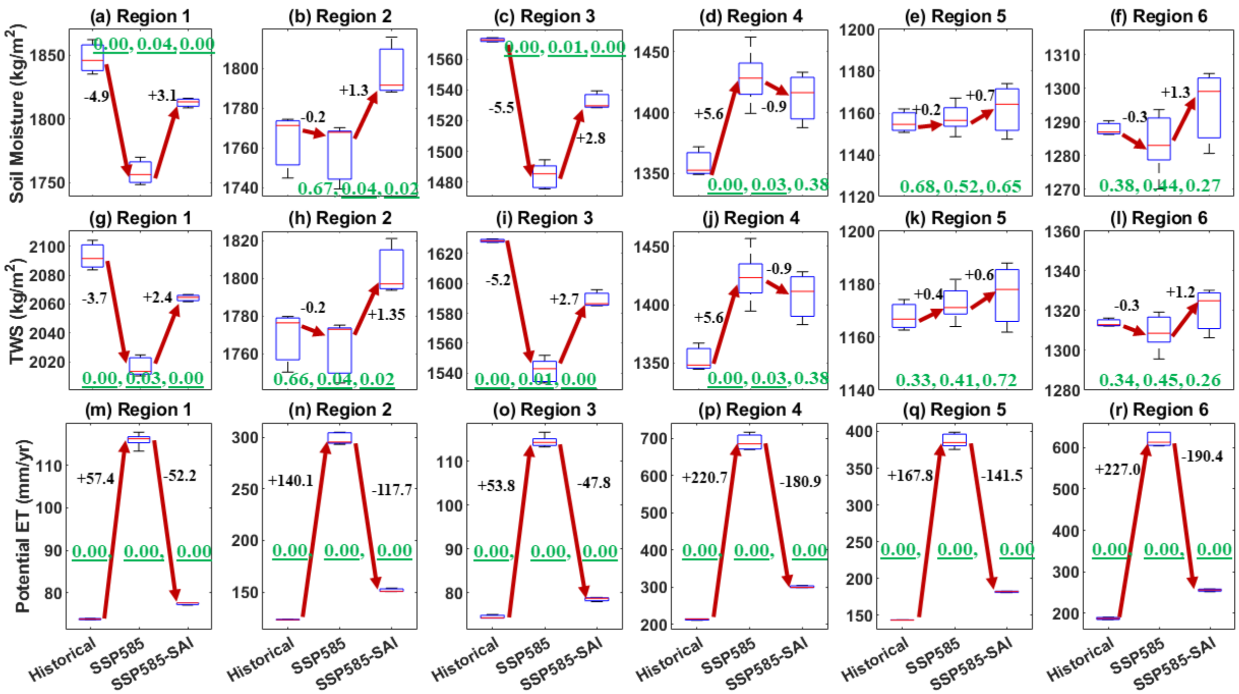

Figure S3. Box and whiskers plot of the changes in soil moisture (upper row), terrestrial water storage (TWS, middle row), and potential evapotranspiration (ET, bottom row) in each region from R1 to R6 row). The titles of each subplot refer to the regions. The median for each experiment is denoted by the red line, the upper (75th) and lower (25th) quartiles by the top and bottom of the box and ensemble limits by the whisker extents. The positive/negative values in black are the change percent relative to the median of the historical 20th period data for each variable, respectively. The three values refer to p-values between historical and global warming, historical and SAI, and global warming and SAI, respectively, obtained from t-test analysis in which the underlined p-values are statistically significant.

Figure S4: For the middle row (temperature) difference plots, the color bar limits should be increased on both ends to better show the regional responses.

Reply: Various limits have been tested; the following is the best.

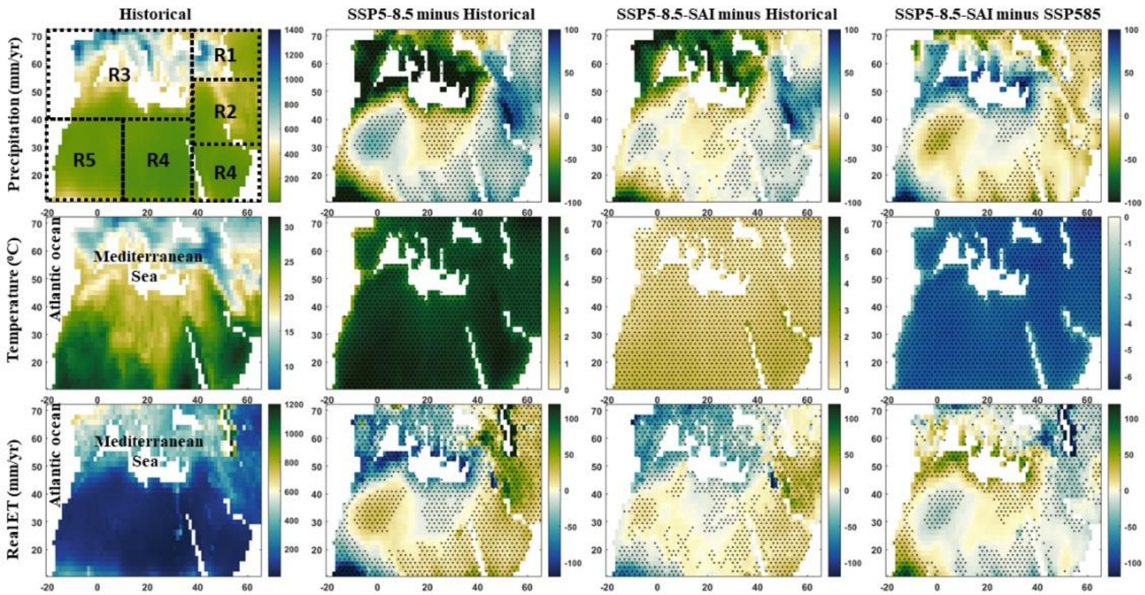

Figure S4. As in Figure S2, but for the variables of precipitation (upper row), surface temperature (middle row), and real evapotranspiration (ET, bottom row).

Data availability: Suggest providing some more information on how to access these specific CESM simulations via the ESGF website (e.g., Source ID, Experiment ID). Tilmes et al. 2020 also has a DOI for the SAI simulations which should be included if those experiments are not on ESGF: https://doi.org/10.26024/t49k-1016.

Reply: we rewrite the data availability as follows:
"The data for CESM2 simulations are publicly available via its website: https://esgf-node.llnl.gov/search/cmip6/. To access these specific data via ESGF website use the Source ID = CESM2-WACCM, Experiment ID=ssp585, and Frequency = mon. The SSP5-8.5-SAI data are freely available at https://www.earthsystemgrid.org/dataset/ucar.cgd.ccsm4.geomip.ssp5.html (https://doi.org/10.26024/t49k-1016)."

Technical corrections:
Line 39: Typo "Projected" should not be capitalized.
Reply: Implemented.

Lines 335-336: I think this should be "return levels" instead of "level returns".
Reply: Implemented.

Lines 335-337: Should these sentences be combined?
Reply: Implemented.

Figure 5: Please add panel labels to the subplots and update caption to "(a to f)".
Reply: Done (please see new Figure 5 above).

Line 397: Typo "EV"
Reply: Corrected.

Line 467: Typo "EV"
Reply: Corrected.

Lines 520-522: I think "SAI" is missing after "with...and without" here.
Reply: Added.